

# BIM as a Structural Safety Study Tool in Case of Fire - BIMSCIP

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## ABSTRACT

In this article, we will discuss how BIM modeling technology can be used to improve the safety of people and buildings in fire-fighting and panic. The objective of this research is to construct an automation methodology of the process of verification of fire compliance, which allows the development of a computation tool more agile and less prone to errors than the manual method currently in use in the Fire Department of the State of Minas Gerais (FDS-MG) in Brazil. The process of creating a plug-in for a BIM environment, a prototype of a computer system called BIMSCIP, will be described and aims to verify the conformity of projects with Fire Department standards. In this work, emphasis will be placed on a particular technical instruction: technical instruction number 06, which deals with the structural safety of buildings in cases of fire. At the current stage the prototype already reads the project and returns consistent results.

**Keywords:** BIM, Structural Safety, Code Checking, Spatial Analysis, Revit.

## 1. INTRODUCTION

One of the important safety aspects of a building in case of fire is the possibility of a safe evacuation, which depends essentially on the human behavior and the necessary time [1]. When considering the necessary timing, the study of Chu

Guaquan, Wang Jinhui and Wang Qingsong [2] concludes that, the fire risk is divided into two parts: probability and consequence. The probability is associated with the number of possible foci of fire, while the consequence is related to the speed with which the fire can be propagated in a certain place.

Building Information Modeling - BIM is today an important tool available for the development of Fire and Panic Systems - FPS. The term BIM, in this context, refers to concepts for the development of a software category, which gathers information of an enterprise from its inception, encompassing the design and construction phases and also during maintenance of facilities (post-construction) up to the end of the building life cycle, with its the demolition [3]. These characteristics give BIM technology great potential for development. This potential is recognized and cited in studies such as "BIM and fire protection engineering" [4], where it is demonstrated that the project constructed from BIM directives only depends on the amount of information it contains so that the analysis is as close as possible of the actual situation of a fire. Thus, projects developed using methodologies to apply BIM concepts allow complex analysis of the data generated through an intelligent processing of this information [5]. For example, the construction of software based on specific rules, to comply with recommendations in case of fire.

In the case of fire and panic prevention and combat, the technical instructions of the Fire Department must be taken into account, which detail a series of requirements that, when performed efficiently, are of fundamental importance for prevention and combat.

In this article, we will discuss the process of constructing a plug-in, called BIMSCIP, which is compatible with Revit

software, whose purpose is to verify compliance of most of the technical instructions of the Fire Department of Minas Gerais [6]. Specifically, emphasis will be given to Technical Instruction No. 06: Structural Safety of Buildings, which will be treated in detailed for this paper. To verify compliance with a Technical Instruction in a project, it is necessary to use a code checking tool (plug-in) developed for automatic checking of the model. An automatic check consists of the validation and verification procedure, which aims to determine if a given content conforms to a particular standard, code, regulation and others. This validation is then performed by predefined criteria and look for results in the form of Yes / No [7].

Although the prototype (plug-in) is still in the initial stages of testing, it has already achieved satisfactory results, returning consistent outputs, and may soon be implemented in full for validation by the Fire Department of Minas Gerais.

## 2. DEVELOPMENT

### State of the art

With the advent of BIM technology, various analytical software and automatic checks have been created to serve diverse areas such as hydraulics [8], renewable energies [9], foundations [10], among others. For all these demands, what is observed in common is the goal of automation and greater agility in the execution of different processes.

It is worth mentioning that, even in CAD platforms, it is possible to perform automatic checking, despite greater difficulties and lower efficiency. Similar to BIMSCIP, a system denominated PROSCIP, was developed for the same purpose of automatically checking compliance of the Fire Brigade of Minas Gerais standards. The software PROSCIP uses 2D models in a CAD environment, which provides less information and presents more difficulties to perform changes in the project. BIMSCIP, on the other hand, is a system developed for a BIM platform, based upon parameterized 3D models, which encompass much more incorporated information.

**Correlated Work:** Regarding the evaluation of fire situations in a BIM environment, we highlight the works that aim to determine the fire resistance of structural elements, using finite element modeling and the exchange of information between studies of thermal behavior of materials and structural analysis software [11,12,13]. Such work shows great importance in the resistance of masonry to fire and can be taken as a basis, for example, in the creation of standards such as IT06, which defines the fire resistance to be considered for each type of masonry.

Also noteworthy are works related to the evacuation process of a place in case of fire. An example is the study that shows that the integration of fire monitoring systems between nearby buildings can reduce fire response time by more than 50% [14]. Another example is the study that suggests that fire alarms could also inform safe escape routes and in how many minutes the building should be evacuated [4]. One can also cite the work of Uwe Ruppel and Kristian Schatz [15], which demonstrate how to create an algorithm to simulate decisions of a human being in case of a fire, since it is impossible in practice to create rescue tests on burned buildings. The proposed simulation is based on games in three dimensions (3D) and considers the five senses of the human being in decision-making. For example, in very hot places, the

algorithm gives the option of avoiding that route, since somebody could suffer burns.

Nevertheless, these works aim to show aspects of the analysis of resistance of the structural elements or human behaviors generated in case of fire, not including fire prevention through automatic checks using resources of a BIM environment, as is the proposal of the present work.

**BIMSCIP:** The BIMSCIP prototype is being constructed with the objective of creating an application capable of performing automated verification of the requirements of each Technical Instruction of the Fire Department of the State of Minas Gerais, that is, for each section of the project a set of rules is analyzed, such as the presence of fire doors, spacing between extinguishers among others.

The project represents an important advance of an earlier CAD system, PROSCIP, which essentially implements similar functions to analyze 2D CAD projects, as those proposed in BIMSCIP. The difference and the substantial advance being the application of BIM concepts and resources and the use of 3D models associated to a BIM environment. The construction of a fire and panic system for a BIM platform is a result of an urgent demand for better and more reliable technologies. The actual BIMSCIP prototype was created, based on the concepts and standards of BIM technology, seeking more practicality in the development dynamics and more reliability in the development of projects.

Because Brazil adopts a prescriptive approach regarding fire safety, unlike countries such as the United States, England and Australia, which are shifting to a performance-based approach [16], a prototype computer system (BIMSCIP) for automatic verification of prescribed standards by the Fire Department is being developed. In addition to using a BIM platform for user interaction and project reading, another important aim of the prototype is to automate the task of designer regarding compliance of standards when developing firefighting and fire prevention projects. Currently, this check is performed manually, which can generate errors and require a lot of time.

This article will deal specifically with Technical Instruction number 06 of Minas Gerais Fire Department, ie, "IT06 - Structural Safety of Buildings". The analysis of structural safety of buildings in case of fire, modeled in BIM a platform, is performed to validate the prototype. Similar studies were not found in the literature review, which highlights the importance of this study.

### Methodology

The methodology used to implement code-checking automation in the BIMSCIP prototype system, to assure compliance with the technical instructions of the Fire Department of the State Minas Gerais, required the following steps to be met:

- I. Analysis of the technical instructions and the respective ABNT<sup>1</sup> standards involved in the process.
- II. Definition of the interaction model with the user. Interface to allow presentation of technical standards, to obtain information to be added by the user and to display results.
- III. Definition of the computational environment for development. The development of BIMSCIP relied on two main programming environments, Microsoft Visual Studio and Autodesk Revit. The Visual Studio environment was used to create a code in C # language. The choice of this language

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<sup>1</sup> ABNT: Brazilian Technical Standards Association. Similar to ISO in the international scenario.

allowed the interaction and interoperability between the team members. The Autodesk Revit .NET application programming environment (API) enabled the custom to develop the prototype BIMSCIP with the construction of directly executable tools inside the Revit platform.

#### IV. Implementation.

#### V. Tests.

The CAD project of the UFMG Engineering School was chosen for the construction of the BIM model, which served as a case study for the implemented methodology, with the adequate adaptation of the parameters necessary for the execution of BIMSCIP.

#### VI. Analysis of Results.

#### Implementation

An important concept of structural safety of buildings is the evacuation time in a fire situation, which should be sufficient to enable a safe evacuation before the collapse of the building. To that end, Technical Instruction 06 (IT06) establishes that the structure must present an equivalent time of fire resistance and fire resistance time of masonry consistent and adequate to the corresponding standard parameter, called Required Fire Resistance Time (RFRT).

Therefore, for programming purposes, IT06 should be modulated according to two annexes:

- Annex A: Approval for Fire Resistance Equivalent Time
- Annex B: Approval for fire resistance time of masonry

**Isolated Areas:** In order for the BIMSCIP system to identify which part of the model is to be analyzed, the "Isolated Areas" function, which uses information from the Revit platform command, is used to discriminate different regions in the BIM model (Figure 1). In this way, when using the platform, the user must first define this delimitation around the BIM model regions, which are relevant and will be analyzed to verify the compliance of Fire Department standards for approval.

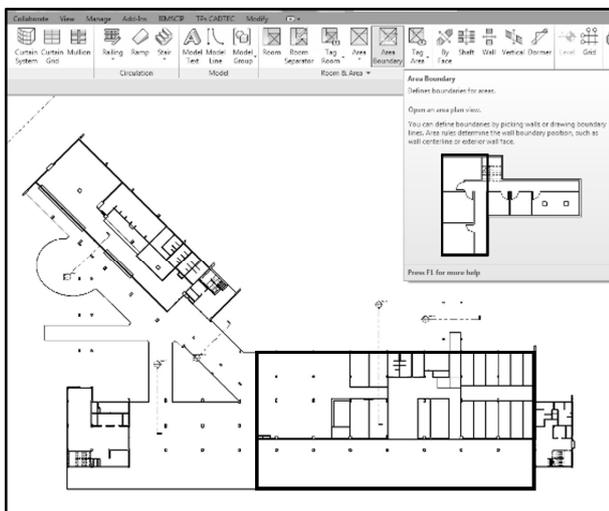


Figure 1 – Isolated Areas delimitation in Revit

One situation that demonstrates the importance of well-defined compartmentalization is the mixed use that some buildings may present. An example would be when a residential building needs to undergo transformations to accommodate a ballroom, an activity that requires approval from the Fire Department, only for the modifications of use of that particular area.

Another example is the situation of a building, which presents multiple compartmentalization, which requires a distinction of what is relevant to the analysis. Since these divisions aid in the distinction of compartments, which in fact require compliance assessment, this enables analysis and approval to occur independently.

It will also be up to the user to define and designate each isolated area, following the standard defined in the instructions, so that the BIMSCIP system can identify the type of use and occupation desired for the place. The identification of the use and occupation of the compartment directly influences the choice of the parameters necessary for the automatic verification, such as the Factor of Resistance to Fire (TRRF).

**Annex A:** For a project to be approved in accordance with the calculated evacuation time parameter, Fire Resistance Equivalent Time - TERF, this parameter must be greater than the standard reference, Required Fire Resistance Time - TRRF, which is tabulated for each type of occupation. That is, the evacuation time, calculated from the characteristics contained in the project, must be longer than the time established by the standard.

For the calculation of the Fire Resistance Equivalent Time, the following formula was adopted by the Fire Department of Minas Gerais:

$$teq = qfi \gamma_n \gamma_s K W \quad (1)$$

In Eq. (1):

teq - equivalent time (minutes).

qfi - fire load (MJ / m<sup>2</sup>).

$\gamma_n = \gamma_{n1} \gamma_{n2} \gamma_{n3}$  - dimensionless coefficient that takes into account the presence of measures of active protection of the building, determined with the aid of tables of the standard.

$\gamma_s = \gamma_{s1} \gamma_{s2}$  - safety coefficient that depends on the risk of fire and the consequences of the collapse of the building, determined with the help of tables of the standard.

K - Factor determined according to the table of figure 2.

W - Factor associated with the ventilation of the environment considered.

E - Correction factor that depends on the material of the structure, determined with the aid of tables of the standard.

Each of the factors specified above was implemented having as input parameters, data and design specifications and as output parameters, the desired results.

The determination of factor K is an example of how the BIM environment was fundamental for the implementation of this formula. Factor K is influenced by the physical properties of the enclosure sealing elements. In this way, families of sealing elements were created to obtain K, such as a fire door, whose parameters specific mass, specific heat and thermal conductivity must be supplied by the user through the BIMSCIP interface according to the characteristics of the existing elements in the project. The creation of interfaces with the BIM platform allows the insertion of information essential to the project by the user during the modeling. Based on the formulas shown in the following table, the system can receive the parameters provided by the user and return the value of K.

$b = \sqrt{\rho \cdot c \cdot \lambda}$ (J/m <sup>2</sup> s <sup>1/2</sup> °C)	K (min . m <sup>2</sup> / MJ)
$\sqrt{\rho \cdot c \cdot \lambda} > 2500$	0,040
$720 \leq \sqrt{\rho \cdot c \cdot \lambda} \leq 2500$	0,055
$\sqrt{\rho \cdot c \cdot \lambda} < 720$	0,070

Figure 2 – Factor K Schedule. Source: Minas Gerais, 2005.

The W factor does not require the creation of specific families for its determination, since the system extracts information from the model by accessing the parameters of the native families of the Revit platform. This factor is influenced by ventilation of the compartment and, to obtain it, the code was developed to filter elements such as windows, floors and floor openings, from which the parameters of the area are extracted to determine W. In addition, the code accesses the height H of the compartment from the height of its walls or its level. The equation for obtaining W is shown below.

$$W = \left(\frac{6}{H}\right)^{0.3} \times \left[ 0,62 + \frac{90 \left(0,4 - \frac{A_V}{A_f}\right)^4}{1 + 12,5 \left(1 + 10 \frac{A_V}{A_f}\right) \frac{A_V}{A_f}} \right] \geq 0,5 \quad (2)$$

In Eq. (2):

H - compartment height (m)

AV - vertical ventilation area - windows (m2)

Ah - horizontal ventilation area - floor (m2)

Af - floor area (m2)

**Annex B:** For a project to be approved by the Masonry Fire Resistance Time criterion, it is necessary that the masonry has a resistance time higher than the Required Fire Resistance Time (RFRT), which is the time reference required by the standard for each type of occupation to ensure a minimum fire resistance time of masonry during a fire evacuation.

The masonry fire resistance time varies according to the material thereof, the thickness and the existence (or not) heat sealing, as shown in Technical Instruction 06 of the Fire Department of Minas Gerais.

Thus, to implement this requirement of verification of compliance with the standard, the proposed methodology adopted the following logic:

- I. Filtering of all existing walls in one compartment;
- II. Verification of the information aggregated to the walls, such as material, thickness and existence of coating;
- III. Crossing the information obtained in the modeling with the information in the table;
- IV. Determination of the Weather Resistance to Masonry Fire;
- V. Comparison with the RFRT previously provided by the standard.

It is important to point out that, in order to facilitate the operation of the developed prototype, the materials made available to the users for the composition of the wall layers were standardized. In addition, in the case of masonry with different values of fire resistance in the same compartment, the system adopts the lowest value among them.

**Organization of the code:** The programming environment used to construct the code and the organization for its development contributed to improve its performance during execution, rationalized the use of repeated codes and facilitated the updating process. With the application of the object-oriented programming paradigm, it was possible to create optimization standards for code execution, such as the pattern of division of the model in isolated areas.

The computational prototype was developed in a MVC - Model-Visualization and Controller standard - to separate the application functions by adopting a three-layer type division: interface, control and persistence, as shown in Figure 3. The

MVC pattern is used to separate application functions as follows:

- Model or interface, which constitutes the interaction layer between the user and the system. It also represents an object storing data and may still have a logic to update the controller data if these are changed. The model stores the information needed for the analyzes to be performed.
- Visualization, which represents the visualization of the data contained in the model
- Controller, which acts on data flow control in the model and updating the view, whenever data is changed, maintaining the separation and persistence between model and visualization. It is noteworthy that this division is very relevant for the reduction of errors and inconsistencies.

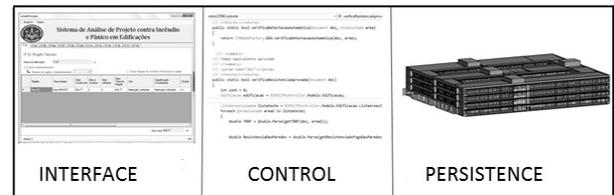


Figure 3 – MVC division.

**The Code:** For a better understanding of the functionality of the code created to verify compliance with Technical Instruction IT06, the function whose purpose is to determine the fire resistance time for masonry is described in detail below. This description uses Figure 4 as reference.

```

BIMSCIP.Persistence.IT06DAOReviz2014
#region getResistenciaAoFogoDasParedes
A public string getResistenciaAoFogoDasParedes(Document doc, AreaIsolada area)
{
    //Adicionado por Bruno
    //Evita que o código seja repetido várias vezes
    B if (area.ResistenciaDasParedes != null) return area.ResistenciaDasParedes;

    C bool meiotijolobarro = this.verificaFormaMeioTijoloDeBarro(doc, area);
    bool umtijolobarro = this.verificaFormaUmTijoloDeBarro(doc, area);
    bool bloco14 = this.verificaFormaBloco14(doc, area);
    bool bloco19 = this.verificaFormaBloco19(doc, area);
    bool revestimento = this.verificaParedesComRevestimento(doc, area);
    bool meiotijoloceramico = this.verificaFormaMeioTijoloCeramico(doc, area);
    bool umtijoloceramico = this.verificaFormaUmTijoloCeramico(doc, area);

    D if (revestimento == false)
    {
        if (bloco14)
        { return "90"; }
        if (bloco19)
        { return "90"; }
        if (meiotijolobarro)
        { return "90"; }
    }

    if (revestimento)
    {
        if (bloco14)
        { return "120"; }
        if (bloco19)
        { return "180"; }
        if (meiotijoloceramico)
        { return "240"; }
        if (meiotijolobarro)
        { return "240"; }
        if (umtijoloceramico)
        { return "360"; }
        if (umtijolobarro)
        { return "360"; }
    }

    E return "0";
}
#endregion

```

Figure 4 – Code Example.

In section "A" of the code, the function is declared as a public text, which is configured by its input parameters doc (document), and by an isolated area previously extracted by the system command to determine isolated areas of the project.

In section "B" a check is made to avoid unnecessary repetition of the command. If the command already presents compiled

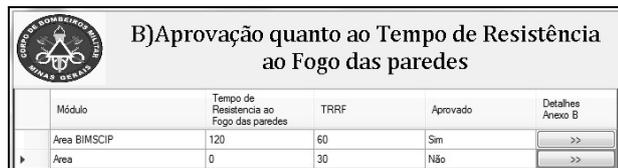
result, this result is returned without the need to execute the other commands. This helps in the agility of the project processing in cases where it is not necessary to recalculate the resistances of the walls and so it is enough that a new function only recovers the value already calculated.

In "C" several commands that return true or false are triggered. Each one is responsible for identifying the wall material, based on names and thicknesses of the layers configured with structural function in the structure profile of the masonry. The presence of coating in the masonry is also verified to take into account the existence or not of layers with a coating function.

At "D" each type of wall is checked in increasing order of fire resistance. This allows the system to quickly find a wall in the defined patterns, which represents the shortest fire resistance time of the compartment, without having to consider the characteristics of the other walls.

In the "E" section of the code, if none of the wall types mentioned in the standard are identified in the project, the command returns a "0" (null). This result indicates that the strength of the walls in the design will never be greater than or equal to the resistance required by the standard, resulting in the disapproval of Annex B of the project and thus the system requests the user to correct this requirement.

**Interface:** The system interface for application of the IT06 instruction in the project was divided between the requirements of annexes A and B. The first screen of each of the annexes allows to distinguish isolated areas within the BIM model and perform the analysis for each area and thus to produce the result of its approval or disapproval, as shown in the results window (Fig. 5).



Módulo	Tempo de Resistência ao Fogo das paredes	TRRF	Aprovado	Detalhes Anexo B
Area BIMSCIP	120	60	Sim	>>
Area	0	30	Não	>>

Figure 5 – Main Window, Annex B – IT06.

Fig. 5 shows that the evaluation process of each compartment is executed independently, which can result in approved and unapproved compartments. In addition, the "Details Annex B" field of the results window can be triggered to open a new window, shown in Fig. 8, containing specific details of the approval or disapproval of the analyzed compartment.

**Tests and Results:** In order to corroborate the consistency of the system's functionality, the BIM model of the Engineering School of the Federal University of Minas Gerais (EEUFMG) (Figure 6) was used, which was built to be the object of study of this work, through the performance of several tests in their compartments.

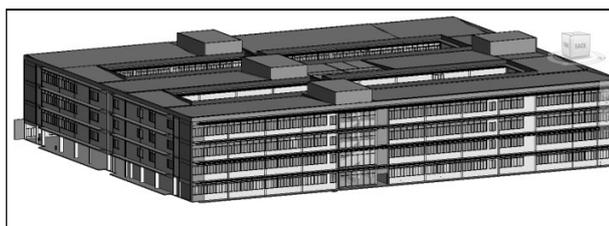
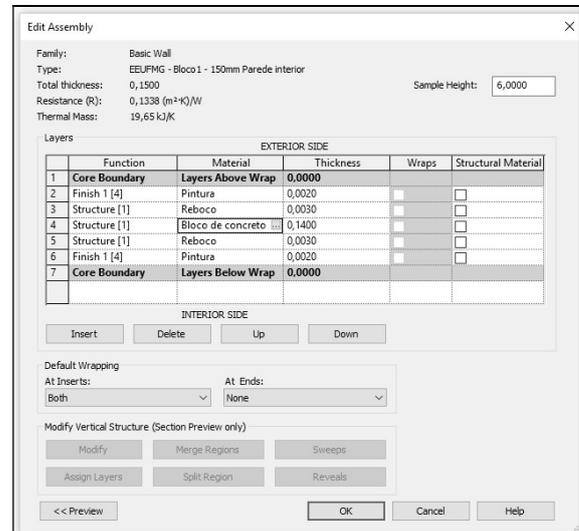


Figure 6- Model of Building 01 of EEUFMG in Rvt.

The BIM model of EEUFMG encompasses entities containing attributes, new materials and specific families of the BIMSCIP system. Figure 7 shows information on layers of an enclosed inner wall delimited in the EEUFMG Block 01 project. In this figure it is possible to identify the material of a structural wall, called "Concrete Block", with a thickness equal to 0.14 m.



Function	Material	Thickness	Wraps	Structural Material
<b>EXTERIOR SIDE</b>				
1	Core Boundary	Layers Above Wrap	0.0000	
2	Finish 1 [4]	Pintura	0.0020	
3	Structure [1]	Reboco	0.0030	
4	Structure [1]	Bloco de concreto	0.1400	
5	Structure [1]	Reboco	0.0030	
6	Finish 1 [4]	Pintura	0.0020	
7	Core Boundary	Layers Below Wrap	0.0000	
<b>INTERIOR SIDE</b>				

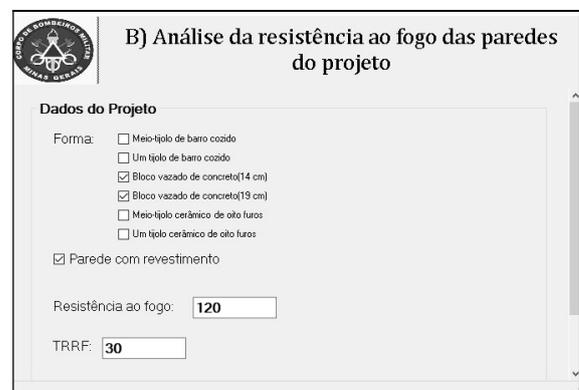
Figure 7- Detail of an internal wall of EEUFMG.

In addition, information is also provided on layers with finishing function, which is interpreted by the system as the wall covering. These data are then filtered and together with others, they are used to calculate several factors, such as the masonry resistance time, which is one of the criteria for approval (or not) of IT06 Annexes A and B for each project.



Figure 8 - IT06 Main Interface.

The results shown in Figure 8, referring to the tests for the structural wall model shows its approval according to the criteria of both annexes A and B, as can be observed.



**B) Análise da resistência ao fogo das paredes do projeto**

**Dados do Projeto**

Forma:  Meio-tijolo de barro cozido  
 Um tijolo de barro cozido  
 Bloco vazado de concreto(14 cm)  
 Bloco vazado de concreto(19 cm)  
 Meio-tijolo cerâmico de oito furos  
 Um tijolo cerâmico de oito furos

Parede com revestimento

Resistência ao fogo:

TRRF:

Figure 9 - Detail interface of Annex B.

In addition, Figure 9 shows details of the approval of this wall according to the criteria of Annex B.

### 3. CONCLUSION

The development of the BIMSCIP system was based on modern concepts of software engineering, object oriented programming and Building Information Modeling (BIM) to automate the code verification procedure in Fire and Panic Systems (SCIP) projects. The purpose of the application (plugin) developed is to meet the demands of two types of agents, namely, the professional who develops fire prevention and fire and panic projects and the regulatory bodies for compliance with fire regulations. Technical Instructions (ITs) of various natures to guarantee the safety of persons and properties in fire situations govern these standards.

In the specific case of this work, only the implementation in the BIMSCIP system of the IT06 criteria was presented, which deal with the fire resistance of structures and masonry.

The BIMSCIP system automates the compliance checking process required for fire and panic (CIP) projects for buildings by applying a code checking to IT06. The application represents a major contribution of BIM technology to the improvement of efficiency and productivity by allowing the reduction in the development time of these projects and of their respective evaluation / approval by the regulatory governmental bodies. In addition, a project developed and approved with the application of BIMSCIP will have a minimized error index, which translates into a significant improvement in the safety index of the building in a fire situation .

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